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# Dynamics of land improvements under land tenure insecurity

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**Abstract:** This article solves and characterises optimal decision rules to invest in irreversible land improvements conditional on land tenure insecurity. The economic model is a normative dynamic programming model with known parameters for the single period returns and transition equations. The decision rules are solved numerically, conditional on alternative scenarios on the likelihood that the lease contract and, thus, farmer access to land is either renewed or expired. The model parameters represent Finnish soil quality and production conditions. The results suggest that irreversible land improvements decrease quickly and the yields decline gradually when the farmer is confronted with land tenure insecurity caused by uncertain renewal of the lease contract.

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**Index words:** Dynamic Programming, land improvements, land tenure insecurity

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## 1. Introduction

Economic literature analysing implications of land tenure insecurity focuses for the most part on developing countries. In these countries, land tenure insecurity has large implications, not only for land improvement, but also on the household and on society welfare as a whole. In many empirical studies, the effects of land tenure insecurity could not, however, be strongly identified in these countries, because household access to farming inputs and output markets can be severely retarded by other institutional, financial and economic factors than by land tenure insecurity alone (Holden and Hailu 2002).

In the context of richer countries, land tenure insecurity has not received much attention in economics literature. Even if land tenure insecurity is not yet a dominating problem in these countries, it may become such, particularly in Less Favoured Areas (LFA), where production costs are high and yields are low. The trend towards more liberalised food market and internationally harmonised agricultural policies decrease Marginal Value Products (MVP) for agricultural inputs in the LFA areas, where farmer options to adjust to these trends are rare. There are good reasons to expect that, in the LFA areas of Northern Europe, land improvements may decrease below the socially optimal levels<sup>1</sup>, if farmers are confronted with significant land tenure insecurity.

In Finland, for example, signals on market failures, caused by land tenure insecurity, are emerging in the agricultural input market and in the amount of irreversible land improvements. Land improvements have generally decreased, and they have decreased most in land parcels which have been cultivated under lease contracts (Yearbook of Farm Statistics 2003; Myyrä *et*

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<sup>1</sup> The socially optimal level of land improvements refers to a level, which is reached in competitive markets equilibrium without land tenure insecurity (Mas-Coell *et.al.* 1995 *pp.* 325-328). The social optimum gives the maximum welfare for society as a whole, including land owners and tenants.

al. 2003). The observed data suggest that market failures resulting from the land insecurity problem have not been solved on land cultivated under lease contracts. The problem is not linked only to yields and food supply but also to efficiency of agri-environmental programs which require irreversible investments on land improvements that have long-payback periods. The potential land tenure insecurity problem on leased land is becoming more and more extensive. In 1995 in Finland, the share of land cultivated under a lease contract was 18% and by 2003, it was 33%.

This article aims to solve and characterise optimal decision rules to invest in irreversible land improvements conditional on land tenure insecurity. The economic model is a normative dynamic programming model with known parameters for the single period returns and transition equations. The decision rules are solved numerically conditional on alternative scenarios on the likelihood that the lease contract and, thus, farmer access to land is expired. The model parameters represent Finnish conditions and they are based on field experiments. The results suggest that land improvements decrease quickly and the yields decline gradually when the continuation of the lease contract is uncertain.

## 2. The model

### *The Bellman equation*

The grain grower optimisation problem is modelled as a recursive finite horizon ( $T$ ) dynamic programming problem that is solved numerically by iterating on the following Bellman's equation (Bellman 1957):

$$(1) \quad V_t(z_t) = \max_{u_t} \left\{ R_t(z_t, u_t) + \beta E_t [ V_{t+1}(z_{t+1}) | \Omega_t ] \right\}, \quad t = 0, 1, \dots, T$$

subject to

transition equations:  $z_{t+1} = g(z_t, u_t)$ , and

initial state:  $z_0$  given

where the optimal value function ( $V_t$ ) is the function of the current state vector ( $z_t$ );  $u_t$  is the control (also called as the decision rule or policy function);  $R_t(.)$  is the single period net return function;  $\beta$  is the discount factor; and  $E_t[.]$  is the conditional expectations operator, conditioned on current information ( $\Omega_t$ ). The optimal value function is constrained by the transition equations, in which  $g(.)$  is a function. It determines the connection between the current state and control and the next period state. The optimal solution is pinned down by the initial state  $z_0$ . It has to be noticed that  $z_t$  and  $u_t$  have separate transition equations and contributions to the net return. This specification generalises the models presented in Kennedy (1986).

The problem is normalised to one hectare and the crop grown is spring barley which is the most common cereal grown in Finland. The soil types are fine-textured *Vertic Cryaquepts*<sup>2</sup> and medium-textured *Oxyaquic Eutrocryepts*<sup>3</sup>. The model represents land that has sufficient quality and the long-run equilibrium is to keep soil *pH* and soil phosphorus status at satisfactory<sup>4</sup> levels from society's perspective, *i.e.* without land tenure insecurity. In more marginal land areas, the land tenure insecurity problem is not the only institutional factor which is decreasing irreversible soil improvements in a high cost country with sparse rural population, such as Finland.

The problem is specified and solved separately for phosphorus and lime applications. The time horizon was set at 100 years which guaranteed that not only decision rules but also stock variables converged.

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<sup>2</sup> Soil taxonomy

<sup>3</sup> Soil taxonomy

<sup>4</sup> The values of *pH* and soil phosphorus status are divided into seven classes as follows: poor, rather poor, fair, satisfactory, good, high and excessive (Viljavuuspalvelu Oy – Soil Analysis Service Ltd. 2000). The class limits are based on extensive number of field experiments. The target class, considered sufficient for normal yields of field crops such as cereals and ley, is satisfactory. Phosphorus is extracted with an acid (*pH* 4.65) ammonium acetate solution, closely resembling the well-known Morgan method, and soil *pH* is determined in water suspension.

Economic implications of land tenure insecurity are modelled through a sequence of fixed duration ( $\tau$ ) land leasing contracts. We simulate a five-year ( $\tau=5$ ) cash lease contract, which is the standard duration for the lease contracts in Finland. Five-year contracts and commitments are often required in agri-environmental programs. Contracts over 10 years are forbidden by Finnish law (Maanvuokralaki). The most common lease payment is a fixed cash payment, since the land owners can auction the cash payments with low information requirements. The short-term land rent can be maximised simply by leasing the land for a farmer who pays the highest cash lease.

The signed contract continues and farmer has certain access to land until the contract's next expiry date  $t=n\tau$ , for  $n=1,2,3,\dots,20$ . At each expiry date  $t=n\tau$ , the continuation of the contract is uncertain and it is renewed by an exogenously given probability  $Prob_{n\tau}$ . Because continuation and expiry are mutually exclusive, the probability that the lease contract expires is  $(1-Prob_{n\tau})$  and, once the contract expires, the single period returns are assumed to stay at zero forever. Thus, the expiry is assumed irreversible so that, if the contract expires, it can never be renewed. Under these conditions, taking the expectations results in the Bellman equation

$$(2) \quad V_t(z_t) = \max_{u_t} \left\{ R_t(z_t, u_t) + \beta Prob_t V_{t+1}(z_{t+1}) \right\}, \quad t = 0, 1, \dots, T$$

$$\text{subject to} \quad z_{t+1} = g(z_t, u_t)$$

$$z_0 \text{ given}, T=100$$

$$\text{where } 0 \leq Prob_t \leq 1 \text{ for all } t=n\tau, \text{ and } Prob_t=1 \text{ otherwise.}$$

The state vector ( $z_t$ ) consists of nutrient stock ( $x_t$ ) and prices of outputs ( $p_t$ ) and the price of the control variable ( $w_t$ ). Prices are assumed deterministic such that the current prices prevail in the future. Thus, the transition equations for prices are simply

$$(3) \quad p_t = p_{t+1} = \bar{p} \quad \text{and} \quad w_t = w_{t+1} = \bar{w}$$

The transition equations (*i.e.* the carry-over effects) for phosphorus and soil *pH* are defined separately in subsequent sections.

The single period net return ( $R_t$ ) is the difference between the single period revenue from selling the yield minus the expenditure of purchasing the control. Because other factors are hold-fixed in the analysis, they can be suppressed and the single period return function is:

$$(4) \quad R_t(z_t, u_t) = p_t y(x_t, u_t) - w_t u_t$$

where  $y(x_t, u_t)$  is a deterministic yield response function, specified separately for phosphorus and lime below. The last term,  $w_t u_t$  is the expenditure of using inputs *i.e.* lime and phosphorus fertiliser.

*Phosphorus (P): yield response and carry-over*

The yield ( $y$ ) and phosphorus control ( $u^p$ ) are expressed as kilograms per hectare (kg/ha), whereas the phosphorus stock ( $x^p$ ) is expressed by milligrams of easily soluble phosphorus per litre of soil (mg/l).

Phosphorus has a direct flow effect and an indirect stock effect on the yield. The direct flow effect is the fraction of the current phosphorus fertilisation that is utilised by the crop at the same period as the nutrient is applied in soil. Indirect stock effect is from phosphorus stock accumulated in soil as unused residues of previous phosphorus applications. It can be depleted gradually without phosphorus fertilisation, reflected as a decline of the soil test P value. It is common that 10%-25% phosphorus taken up by a crop comes from the same year's fertiliser application, the rest originating from the stock of the soil build up earlier (Sharpley 1986). The yield response to the phosphorus stock in the soil is described by a Mitscherlich function (Myyrä *et al.* 2003)

$$(5) \quad y(x_t^p, u_t^p) = 3367 - 2492 e^{-0.37 x_t^p}$$

and the yield response to phosphorus application ( $u^p$ ) is specified as an exponential function (Saarela *et al.* 1995):

$$(6) \quad dy(x_t^p, u_t^p) / du_t^p = 5.85 + (21.7 - 0.414x_t^p)\sqrt{u_t^p} + (17.01u_t^p - 0.1817) \frac{u_t^p}{x_t^p}$$

The transition equation is assumed to be

$$(7) \quad x_{t+1}^p = 0.01u_t^p + (1 - 0.02)x_t^p$$

The transition equation imposes an average annual decay rate of 2% in the stock of phosphorus, which can be seen when  $u_t^p$  is put to zero. The assumption is made, even if it is known that the decay rate has a large annual variation (Yli-Halla 1989). The initial state for the stock is given as  $x_0^p = 7.8 \text{ mg/l}$ , which was estimated to be an average on leased plots in central and northern Finland (Myyrä *et al.* 2003).

The fit of the equation system matches to the generalised results of Mäntylähti (2002) so that an annual phosphorus application of 14-15 kg/ha converges the phosphorus stock at around 7.5 mg/l. Less than 15 kg/ha phosphorus application is a common standard in meeting the terms of the Finnish agri-environmental program. The resulting average yield level is 3,500 kg/ha, which also corresponds to the observed average yields of spring barley in Finland (Yearbook of Farm Statistics 2003).

*Lime (L): yield response and carry-over*

The liming control ( $u^l$ ) is measured as tonnes per hectare (t/ha) and the stock of lime ( $x^l$ ) is measured in terms of soil  $pH$ . Liming has only an indirect effect on yield via soil  $pH$ . The yield response to the soil  $pH$  is described by Mitscherlich function (Kempainen 1993; Myyrä *et al.* 2003)

$$(8) \quad y(x_t^l, u_t^l) = 3748 - 29147862 e^{-3.85 pH_t}$$



The transition equation describing the carry over effect and the effects of liming to the soil  $pH$  is (Kemppainen 1993)

$$(9) \quad x_{t+1}^l = pH_{t+1} = 0.049u_t^l + pH_t - 0.015$$

With no liming, the average annual decay rate in the soil  $pH$  is 0.015  $pH$ -units, which implies that annual amount of liming required for maintaining the existing  $pH$  level is on average 0.3 tonnes per hectare. The initial state is imposed at  $x_0^l = pH_0 = 5.8$ , which was estimated to be an average on leased plots in central and northern parts of Finland (Myyrä *et al.* 2003). The prices and the scope of the model are summarised in *Table 1*.

*Table 1.* Prices and the scope of the optimisation problem.

Price of barley <sup>a</sup>	110 /tonne
Price of phosphorus <sup>a</sup>	1,220 /tonne
Price of lime <sup>a</sup>	
if applied 1-3 tonnes/ha	42.69 /tonne
if applied 4-15 tonnes/ha	33.61 /tonne
Discount factor ( $\beta$ )	1/1.05
Time horizon ( $T$ )	100 years
Duration of single contract ( $\tau$ )	5 years

<sup>a</sup> The prices are farm gate ones. The price of liming includes also distribution on the field because the standard is that the distribution is bought from a contractor and therefore does not involve sunk cost from the farmer perspective. Distribution incurs extra cost per tonne at low application levels.

### 3. Results

#### *Phosphorus*

When there is no land tenure insecurity, *i.e.* where the land is owned by the farmer or the lease contract is repeatedly renewed with certainty, the steady state equilibrium<sup>5</sup> for the phosphorus application is estimated to be 18 kg/ha (*Figure 1*). The likelihood for expiry of the lease contract has considerable effects on the optimal phosphorus fertilisation, particularly, when the contract is reaching the edge of expiry/renewal date. If, for example, the odds are slightly in favour of contract renewal ( $Prob=0.6$ ), the optimal phosphorus fertilisation stays between 10 and 11 kg/ha until the third year before the renewal date. This level of application is as much as 39% - 44% lower than the long-run equilibrium without land tenure insecurity. Thereafter and towards the end of the current contract, the phosphorus fertilisation drops to 8-9 kg per hectare. If the expiry of the contract is certain, the phosphorus fertilisation goes towards 2 kg/ha quickly as the expiry date approaches.

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<sup>5</sup> Which we call as the socially optimal level in chapter 1.

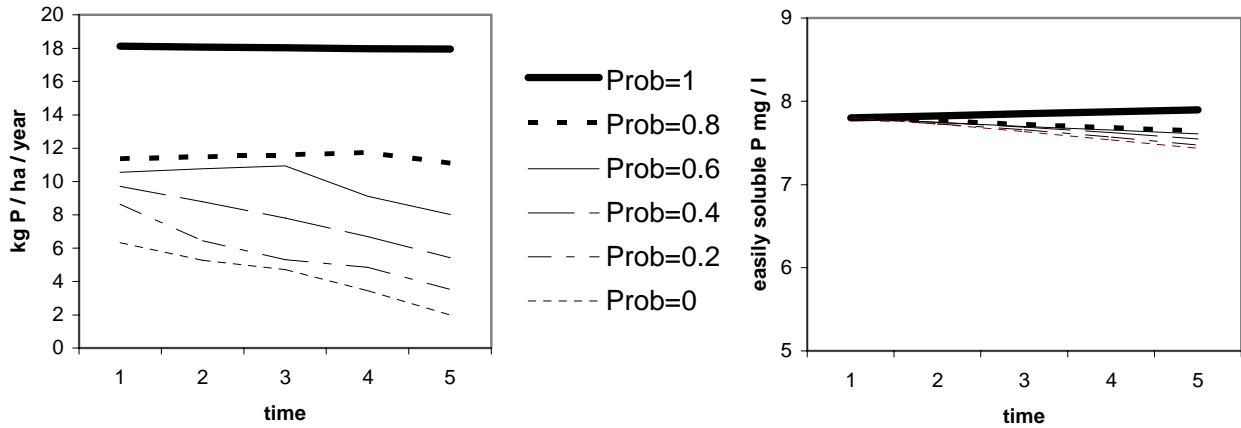


Figure 1. Phosphorus fertilisation ( $u_t^p$ ) (left diagram) and consequent values of easily soluble P in soil (right diagram) as a function of the remaining duration in the contract before its expiry/renewal date, conditional on the probability ( $Prob$ ) that the contract is renewed at the expiry date. If  $Prob=1$  ( $Prob=0$ ), the contract is certain to be renewed (terminated). Please note that the phosphorus state ( $z_t$ ) is not yet converged by the period of  $t=5$ . The crop is spring barley.

When there is no land tenure insecurity the steady state (*i.e.* the state which you have to keep to achieve the maximum profit) for soil phosphorus is 8.5 mg/l, which is substantially below the amount needed for producing the maximum yield (13 mg/l)(Figure 2). If uncertainty over the continuation of each five-year contract is high so that the odds are strongly against of contract renewal ( $Prob=0.2$ ), the steady state soil phosphorus is estimated at 5.5 mg/l, which definitely represents a lower soil phosphorus status that required for the maximum yield. Even if the odds are slightly in favour of the contract renewal ( $Prob=0.6$ ), the steady state soil phosphorus decreases to 6.8 mg/l. The analysis is based on the estimated<sup>6</sup> connection between soil phosphorus and expected yield presented in equation 5. In equation 5, decreasing soil phosphorus has quite a small influence to yield until the soil phosphorus

<sup>6</sup> Functional form is a fundamental question in estimating the connection between fertilisation and yield (Bäckman *et al.*, 1997). A thorough discussion about the functional specification can be found in Myyrä *et al.*, (2003).

decreases below 7 mg/l. When the soil phosphorus status declines below 7 mg/l, the yield decreases rapidly. Thus, the profit maximising soil phosphorus levels are substantially lower compared to the maximum yield levels under high uncertainty over contract renewal ( $Prob < 0.4$ ).

When the phosphorus state is converged, the steady state equilibrium for the phosphorus application is estimated between 16 and 18 kg/ha (*Figure 2*). The optimal use of phosphorus fertiliser has decreased slightly, because of increased phosphorus stock. Changes, caused by uncertainty, in phosphorus stock have also implications to the tenants fertilising behaviour. There is incentive to use phosphorus fertiliser at the beginning of the lease contracts, even if uncertainty over continuation of each five-year contract is high ( $Prob=0.2$ ), because of the low levels of phosphorus stock. Incentives disappear sharply as the expiry date approaches (*Figure 2*).

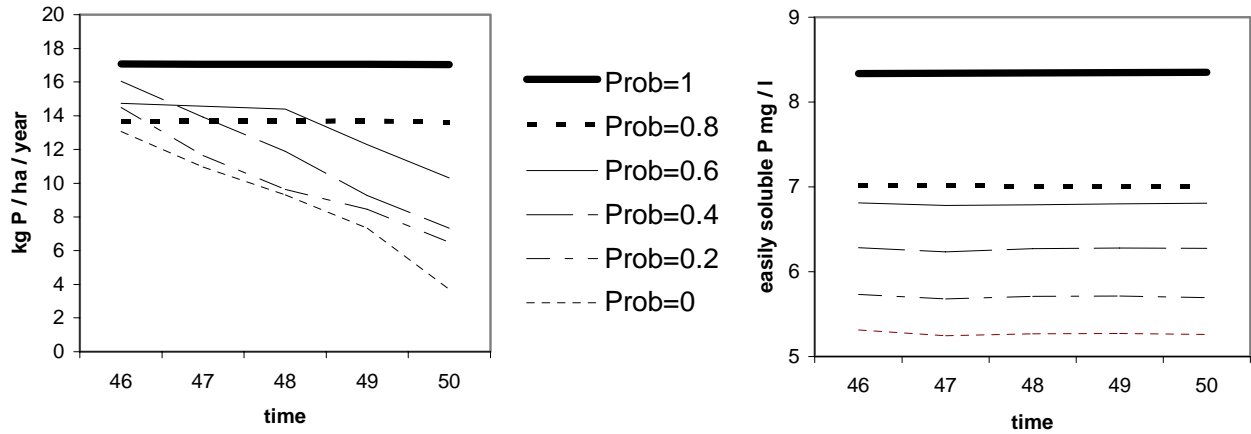
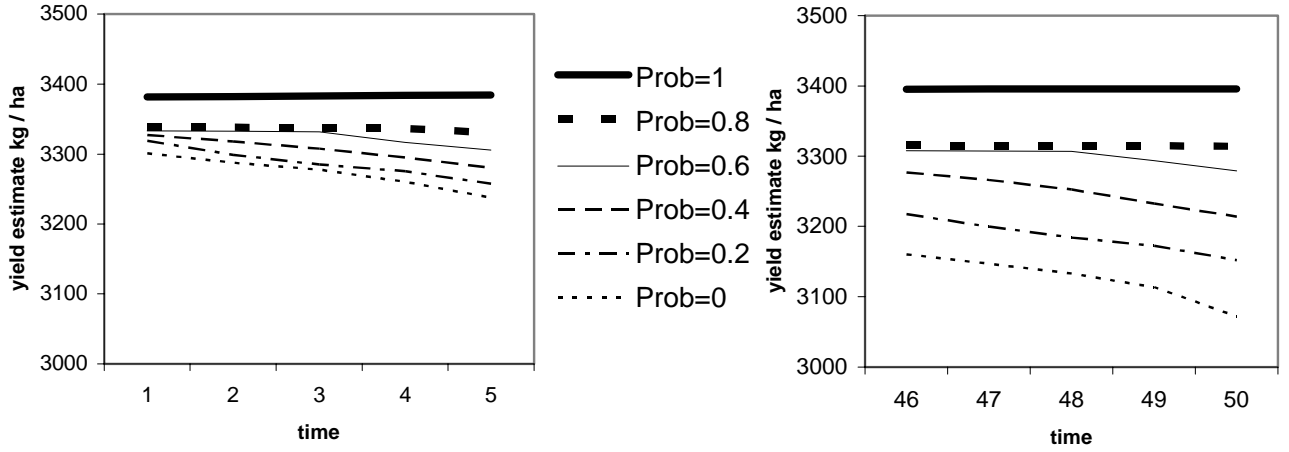


Figure 2. Phosphorus fertilisation ( $u_t^p$ ) (left diagram) as a function of the remaining duration in the contract before its expiry/renewal date and converged values of easily soluble P in soil (right diagram) , conditional on the probability ( $Prob$ ) that the contract is renewed at the expiry date. If  $Prob=1$  ( $Prob=0$ ), the contract is certain to be renewed (terminated). The phosphorus state ( $z_t$ ) is converged during  $46 \leq t \leq 50$ . The crop is spring barley.

Gradually decreasing soil phosphorus stock will eventually decrease yields (*ceteris paribus*). Figure 3 traces out the yields during two five-year contracts, which are located in the optimisation horizon at  $1 \leq t \leq 5$  and  $46 \leq t \leq 50$ . In the latter period, the soil phosphorus has converged to steady state values as given in Figure 2. When the land has been cultivated under several subsequent five-year lease contracts and the likelihood for contract renewal has been repeatedly at stake, the yield will start to decrease significantly and converge to around 3,100 kg/ha. The yield decrease from the 3,400 kg/ha steady state equilibrium without land tenure insecurity is 300 kg/ha and in relative terms 10 per cents. Even if the odds are slightly in favour of contract renewal ( $Prob=0.6$ ) the steady state yield will be decreased by 100 kg/ha (3%) to 3,300 kg/ha.



*Figure 3.* The predicted yield response to optimal phosphorus fertilisation under alternative probabilities ( $Prob$ ) for renewal of each five-year lease contract (*ceteris paribus*). The phosphorus state ( $z_t$ ) is converged during  $46 \leq t \leq 50$  (right). The crop is spring barley.

#### *Liming and soil pH*

Liming represents even a longer term land improvement than phosphorus fertilisation. Liming is also to some extent lumpy so that it is expensive to distribute small amounts of lime (see the price thresholds in *Table 1*). Therefore, if the initial soil  $pH$  is in biological target range, which is in our simulations 5.8, the land tenure insecurity does not make a difference in the optimal liming rules (*Figure 4*). It does not pay to distribute lime on land with  $pH$  level exceeding 5.8, except when the farmer access to land certainly continues, either through repeated contract renewals or land ownership. In this case the decision rule converges with optimal behaviour around long-run equilibrium without land tenure insecurity, which is also optimal for the society. We have analysed crop farming and more precisely spring barley. More demanding crops would likely benefit from higher  $pH$  values.

But when the initial  $pH$  level decreases and soil acidity increases, decisions to lime diversify according to the uncertainty over continuation of the lease contract (*Figure 4*). If

the contract is certain to expire, it pays to lime at the beginning of a five-year contract only if the soil  $pH$  is below an extremely low value of 5.2. If the odds are slightly in favour of contract renewal ( $Prob=0.6$ ) it pays to lime at the beginning of the five-year contract if the soil  $pH$  is below 5.6.

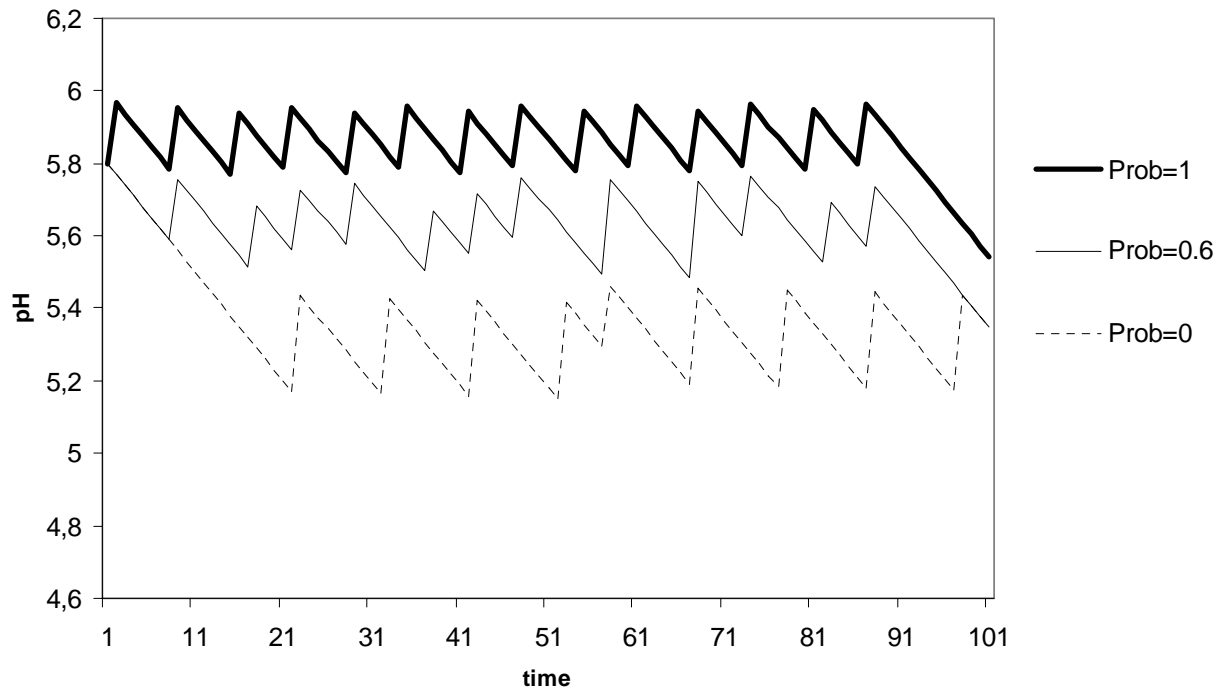


Figure 4. Development of soil  $pH$  in a sequence of 5 year lease contracts, conditional on alternative contract renewal probabilities ( $Prob$ ). The upward sloping jumps in soil  $pH$  indicate points where lime is applied. Downward sloping line traces the soil  $pH$ , when lime is not applied.

The steady state, long-run equilibrium, without land tenure insecurity is to maintain soil  $pH$  above 5.8, representing a “satisfactory” or “fair” soil  $pH$  status in the soil type studies. The level is in internationally compared quite low. When the likelihood for contract renewal is positive (e.g.  $Prob>0.5$ ), it is still advantageous to maintain the soil  $pH$  above 5.6. Optimal timing is to apply liming immediately after the new contract is signed. Nevertheless, when the likelihood for contract renewal decreases and the odds are in favour of contract

termination ( $Prob < 0.5$ ), the soil  $pH$  is allowed to decrease below 5.4, which in soil studies most commonly represents the fertility class “rather poor”<sup>7</sup>. This is below the biological optimum for barley.

Neglected liming results in gradually decreasing soil  $pH$ , which will eventually decrease yields (*ceteris paribus*). Figure 5 traces out patterns of consequent five-year contracts, which add up to a 100 year period. When the land has been cultivated under several subsequent five-year lease contracts and the likelihood for contract renewal has been repeatedly at stake, the yield will start to decrease significantly and converge to around 3,590 kg/ha. The yield decrease from the 3,730 kg/ha steady state equilibrium without land tenure insecurity is 140 kg/ha and, in relative terms, 4 per cent. If the odds are slightly in favour of contract renewal ( $Prob = 0.6$ ) the steady state yield will be decreased only by 30 kg/ha (0.8%) to 3,700 kg/ha.

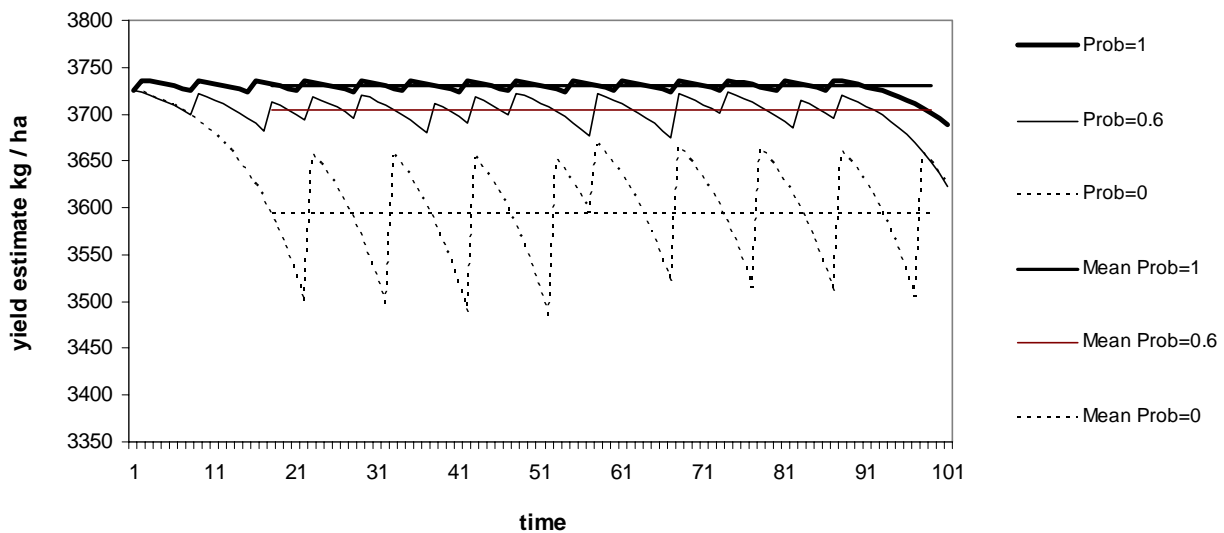


Figure 5. Predicted yield response to optimal liming under alternative probabilities ( $Prob$ )

for a renewal of each five-year lease contract (*ceteris paribus*). The means are computed over the years  $t \geq 18$ .

<sup>7</sup>

The class limits depend on the particle size distribution and the organic matter content of the soil.



Conformity of the predicted yield in two separately calculated models is not complete (*Figures 2 and 5*). This is because of separate data sources for the yield response and carry-over parameters. Still both models give signals that land tenure insecurity harms the goal to increase productivity in Finnish crop farming.

#### **4. Concluding remarks**

The results of our normative dynamic programming model, solved with known parameters, highlight that optimal decision rules on irreversible land improvements, with long pay-back periods, substantially diversify according to the extent of land tenure insecurity. Land improvements decrease below the optimum for society, when the likelihood for contract renewal decreases and the likelihood of having future access to land decreases. Therefore, the current tendency of gradually increasing the share of land cultivated under simple fixed duration cash lease contracts poses a problem in maintaining land improvements and soil fertility that are sufficient for maximising society's welfare. This will finally turn into decreased yields and weakened supply for food. Furthermore, the incentive problem caused by land tenure insecurity will hamper the efficiency of environmental programs to decrease nutrient runoffs since the standard is such that implementing these programs require irreversible investments on land with long-payback periods.

The results also raise justified concerns and reasons to expect that prominent land tenure insecurity is posing more severe problems to land improvements than currently revealed by the observed statistics on soil *pH* and the stock of phosphorus in soil (soil phosphorus status). In positive approaches, the insecurity problem has had statistically significant effects on the soil *pH* and soil phosphorus, but the diversification in the stock variables according to land tenure status (leased *vs.* owned) has, so far, been modest (Myyrä

*et al.* 2003). The modest differences found in the positive modelling may have been shrink by data censoring. For example, the time when the land has come to the rental market was unobserved in the statistical tests of Myyrä *et al.* (2003).

Nevertheless, substantial implications, as suggested by our normative model, are supported by aggregate market behaviour even if this behaviour cannot, due to data limitations, be directly linked to individual plots of certain tenure status. The demand for lime and phosphorus fertilisers has been decreasing rapidly as the share of land cultivated under lease contracts has been increasing. It has to be noted, however, that market trends have been affected also by other institutional and economic factors, such as decreasing Marginal Value Product for lime and phosphorus.

Our results hold only to cash lease contracts where the likelihood of contract renewal is exogenous. The results do not generalise for repeated dynamic games, in which the reputation effect has significant implications for optimal decision rules. Thus, our analysis does not account for the possibility that land improvements may be used to increase likelihood for contract renewal.

One of the main goals of the Common Agricultural Policy (CAP) is to increase productivity in agriculture. The results signal that reaching this goal may be seriously hampered by gradually increasing land leasing unless land tenure insecurity problem can be solved by better contract design.

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